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SWOT analysis for the development of photovoltaic solar power in Africa in comparison with China

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ABSTRACT

Development of solar power becomes a necessary measure to combat global climate change and local environmental pollution in the world. In Africa, solar power resource is abundant, and deployment of solar photovoltaic (PV) offers a new opportunity for both economic growth and low-carbon development. Using an approach of SWOT analysis, we investigate the internal strengths and weaknesses, and the external opportunities and threats for PV solar power development in Africa. Particularly, factors are examined and discussed for African countries in terms of their internal strengths of rich solar resource, vast land, suitable application for distributed PV power systems; their weaknesses of small scale of renewable energy investment, shortness of foundation for the PV industrial chain, insufficient awareness of social and environmental benefits of solar PV; their external opportunities of increasing gap between energy supply and demand, raising global awareness of Climate Change, rapid decrease of PV price, as well as their external threats of dominant position of the fossil fuels, potential environmental impacts related to the solar PV development, and discontinuity of energy policies. The analysis particularly emphasizes on a new opportunity for African countries to develop their solar power resource through mutually beneficial cooperation between Africa and China within the framework of the Belt and Road Initiative (BRI).

1. Introduction

As the second largest continent with a population of about 1.3 billion, Africa has become a new economic engine in the world, with vast potential for growth in the near future (Onuoha, 2015). Nowadays, the severe power shortage (Chakamera and Alagidede, 2018) it faces makes the construction of energy infrastructure become one of the prior tasks of African development. As the disparity between the supply and demand of conventional energy is increasingly aggravating (Akinlo, 2008; Wolde-Rufael, 2006) and the climatic and environmental issues are increasingly prominent (Bartniczak and Raszkowski, 2019), most African countries start to seek new energy alternatives from the perspective of sustainable development and energy security.

The global supply of electric power increased by 2.8%, from 24.9 PWh in 2016 to 25.6 PWh in 2017 (British Petroleum, 2018b). Nearly 40% of such growth is contributed by renewable energy, mainly contributed by wind energy (163TWh) and solar energy (114 TWh). In 2017, the worldwide installed capacity of the PV solar power increased by about 100 GW, of which approximately 50 GW was deployed in China, while only 3.63 GW in Africa (Global Energy Statisitcal Yearbook, 2018). The increase in the total global PV power generation benefited from the supportive government policies in the leading countries (such as China, USA, India, Germany, Australia etc.) of solar power development in the world (Abolhosseini and Heshmati, 2014; Ciarreta et al., 2017). Another important reason was the decline in capital costs of solar farms due to the advancement of PV technology (Finance, 2018). Bloomberg New Energy Finance (BNEF)predicted that the global installed capacity of PV solar power would reach 522 GW by the end of 2018, and 637 GW by 2019. According to a report of Green Technology Media (GTM), by the end of 2018, there would be 13 countries each with an installed capacity of PV solar power exceeding 1 GW, a considerable improvement compared to the case of 8 countries in

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2017. Although the installed capacity and power generation level of PV solar power in Africa are in the start-up stage, the future PV solar power development has attracted wide attention.

In this study, we adopted a SWOT approach to investigate the internal strengths and weaknesses, as well as the external opportunities and threats for PV solar power development in Africa. All the data adopted in this analysis were collected through onsite interview, documents of projects, and existing literature. Our analysis suggests that it is a critical time for Africa to seriously consider exploring its locally available and abundant solar PV resources given its remarkable disparity between demand and supply of energy, as well as increased severity of the threat associated with climate change. At the same time, the possible negative impact of development of solar power on the ecological environment also needs to be proactively addressed. The technology for Africa to explore solar PV is comparatively competitive and commercially mature in the international market. Given the strategically important position of Africa in the global politics and economics, the continent becomes a focus of interest for various countries in the world, especially for the "Belt and Road" initiative (BRI) proposed by China. Africa can strive to seize the development opportunities brought by the BRI through international cooperation. The consistent policy guidance and support from governments are urgently required to facilitate the sustainable and long-term development of solar PV in Africa.

2. Literature review

A number of studies have analyzed the opportunities and challenges for the development of solar power in Africa from the perspective of policies or economic growth. Pillot (Pillot et al., 2017) analyzed how policies affect the solar power development in Sub-Saharan Africa with the global energy policy framework. MercèLabordena (Labordena et al., 2017) examined how political and economic barriers impact on the development of concentrating solar power (CSP) in Sub-Saharan Africa. Zubi (Zubi et al., 2018) suggested the solar home systems may be a cost-effective way to overcome the domestic energy poverty in developing regions of Sub-Saharan Africa. Brunet (Brunet et al., 2018) has conducted a review on the development of solar energy in Africa from 1992 to 2016, providing a comprehensive understanding of the contribution of PV solar power to the continent's sustainable development. Carole Brunet (Brunet et al., 2018) demonstrated the feasibility of developing solar PV in Africa, where is confronting a severe energy deficit. Amoah (Amankwah-Amoah, 2015) took the technology leapfrogging of solar power to identify five models for developing solar PV in Africa and further pointed out the challenges for expanding to large scale. Quansah (Quansah et al., 2016) discussed the barriers of development of solar PV faced by countries in Africa and recommended countermeasure by adopting distributed and decentralized PV systems in remote countryside. However, these studies tend to emphasize specific factors influencing the solar power growth in Africa and fail in emphasizing on the systematical framework for its sustainable development.

3. SWOT analysis for the development of PV solar power in Africa

The framework of the SWOT analysis in this study is presented Fig. 1 in the form of a quadrant map concerning the PV solar power development in Africa. The section proceeds in detailed discussions on those factors.

3.1. Strength analysis

3.1.1. Rich solar resource in Africa

One-half of the total solar radiation on the earth locates in Africa, and 80% of the African land surface has annual radiation larger than 2000 kWh/m^2, comparing to about 40% of the land areas with the similar solar irradiation condition in China. The solar power resources in the Sahara and the East African Plateau are particularly abundant, with the annual radiation of as high as 2500 kWh/m^2. As illustrated in Table 1, solar power resources exhibit remarkable advantages in terms of total potential in Africa in comparison with other renewables including wind energy, hydro-energy and geothermal energy (African Development Bank Group, 2013). More detailed information on global solar irradiation intensity can be found in open solar energy data platform (Solargis, 2018).

3.1.2. Rich land resource in Africa

Differing from power generation using conventional fossil energy, PV solar power generation occupies a relatively large land area per unit capacity. The 1 MW solar PV system using the polycrystalline PV module covers about 1 ha, while 50 MW oil-fired requires only 2.5 ha and 250 MW coal-fired power plants 15 ha (Dongfang Electric, 2016, 2018a,2018). The total African population amounts to 1.3 billion, similar to China, but they are distributed over a continent of 30.2 million square kilometers, more than three times Chinese land area. Most of the African countries are sparsely populated and have vast plains and deserts in the territory, which makes it suitable for mass exploitation of PV power farms in Africa.

3.1.3. Suitable application for distributed PV power systems

Distributed PV solar power systems offer a cost-effective supply for in-situ use of electricity in rural places of Africa (Opiyo, 2016), where extension of the electric grid system is costly (Opiyo, 2016). In some rural areas of Africa, the cost of transmission between the local and main grids is as high as 10,000 USD per kilometer, while the average power supply cost of the global power grid is only 900 USD per kilometer (TaoWang Yuechen, 2016). The long-distance power transmission in Africa is also accompanied by the power loss of USD 5.9 billion every year (TaoWang Yuechen, 2016). In order to increase electricity accessibility for the rural population, many African countries encourage the development of off-grid solar PV projects, together with small-scale hydro, wind and biomass power generation (Taele et al., 2012). Taking Angola as an example, in April 2017, the country invested in the construction of 12 off-grid PV solar power stations in 11 provinces to meet the demand for electricity of rural people. The electricity of distributed solar PV systems can be produced and used locally, reducing the requirment of long-distance transmission. Given the insufficient grid infrastructure, the off-grid distributed PV solar systems could prove to be a more affordable option in Africa (Njoh et al., 2019).

3.2. Weakness analysis

3.2.1. Small scale of renewable energy investment

In 2017, the global investment in renewable energy increased to 279.8 billion USD. Therein, China amounted to 126.6 billion USD, taking up approximately 45% of the global total (United Nations Environment Programme, 2018). In contrast, the total renewable investment in Africa was only 3.5 billion USD, occupying less than 2% of the global share (Yonghong, 2013). Furthermore, the investment in renewable energy in Africa occurs in a small number of countries (Pueyo, 2018). Many African countries have not given a full play of the investment potential of renewable energy, although the many pledges were made by donors and international financiers (Pegels, 2010). A main reason relates to the risk for recovering the investment. Renewable energy including solar power is capital intensive, and the large bulk of investment are committed at the initial stage the projects. In addition, the solar PV panels and balance of system are purchased in the international market and paid in foreign currency, but the project revenues are usually transacted in local currency (Mutanga et al., 2018). The currency risk may become another barrier for large-scale development of solar power in Africa.

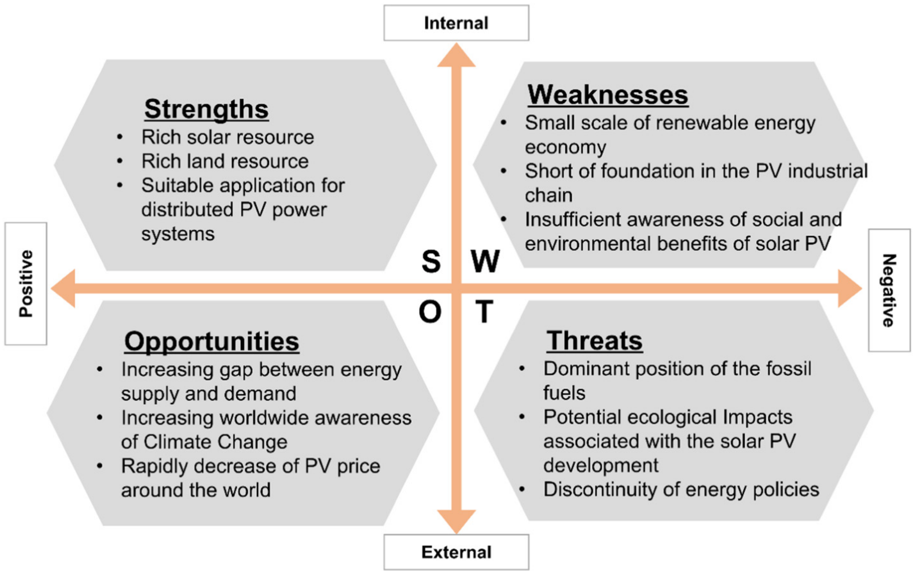

Fig. 1. SWOT analysis quadrant map for the development of PV solar power in Africa.

Table 1
Potential of the renewable energy in Africa (African Development Bank Group, 2013) (PWh/year).

Items	East–Africa	Middle-Africa	North-Africa	South-Africa	West-Africa	Total-Africa
Wind	2.5	0	3.5	0.016	0.005	6
Solar	30	10	55	28	50	160
Biomass	2.074	0.066	0.006	0.065	0.076	2.259
Geothermal	0.008	0	0	0	0	0.008
Water	1.178	1.057	0.078	0.026	0.105	2.86

3.2.2. Short of the foundation of the PV industrial chain

Most African countries have not yet mastered the key technologies of solar PV (Jadhav et al., 2017). PV module processing, inverter production, installation, operation and maintenance are still relying on imports from international markets. By 2017, about seven companies with MW-scale manufacturing capability had been established in South Africa (namely, Solaire Directe, Art Solar, ILB Helios, Jinko Solar, Sunpower, Suntech, SMA solar), and ART Solar is the only state-owned company by the country. However, ART Solar produced only 40 MW PV panels in 2017, which relies on the technology supplied by Swiss and German equipment manufacturers (Baker and Sovacool, 2017). Although South Africa established a national research center to study solar PV technology in 2005 (Jadhav et al., 2017), the foundation of the PV industrial chain has not been fully established.

3.2.3. Insufficient awareness of environmental and social benefits of solar PV power

Differences in public awareness of the environmental and social benefits of solar PV power exist between developing and developed countries (Sulemana et al., 2016). In many places in Africa, the public concern more about the practical problems relevant to people's livelihood and physical health. As a dilemma stated in the Environmental Kuznets Curve (EKC) hypothesis, many African countries face the "too poor to green" situation (van Kempen et al., 2009; Martlnez-Alier, 1995). Benefits of low-carbon energy development are not fully recognized by the public in Africa in terms of increasing the employment rate, boosting the local economy and improving the public's living standards (Perez et al., 2007). The report from the China PV Industry Association demonstrated that, in 2017, China's PV industry attracted the investment of RMB 409.1 billion in PV power station and turned in the relevant industry corresponding taxes of RMB 170.8 billion. Enterprises with 30 MW PV output capacity in the PV industry have created more than 2 million jobs, and the development of the distributed PV, especially rooftop household PV, facilitated more than 10,000 small and micro enterprises in China, which created ten thousands of jobs for rural areas (China PV Industry Association, 2018). Such environmental and social benefits of solar PV power could also be realized in Africa.

3.3. Opportunity analysis

3.3.1. Increasing gap between power supply and demand in Africa

Africa has the lowest total and per capita consumption of electricity among all the continents (except for the Antarctic) in the world. As shown in Fig. 2, the per capita electricity consumption was 14,640 kWh in North America, but in Africa it was as low as 695 kWh in 2016, ranking at the bottom in the world. The World Energy Outlook 2018 from International Energy Agency (IEA) shows that electricity access is still the primary challenge in Sub-Sahara Africa, where 42% of the population is not connected to the grid, and the rural access ratio is only 16%.

On the other hand, the local supply of fossil-based sources is insufficient for Africa's current demand for energy, and the future supply-demand gaps would become even wider given the increasing energy use for the projected economic growth (Fereidoon, 2013). The 2018 Energy Outlook by BP indicates that oil output in Africa is expected to be far lower from meeting its consumption demand for petroleum products during 2016–2040. The rising energy consumption in Africa has caused the increasing deficit of oil in import and export trade (Fereidoon, 2013). Power shortage and backward infrastructure are believed to seriously hinder the necessary education and business activities in some African countries. Many government departments and large companies then started to look for alternative energy solutions (Fereidoon, 2013). The locally available solar power can play a critical role in this event.

3.3.2. Increasing worldwide awareness of climate change

In 2015, the former United Nations (UN) Secretary-General, Ban Ki-moon pointed out during the Paris Climate Change Conference, "In the face of the challenge of global low-carbon development transformation, development of solar energy resources will become an opportunity for the rise of Africa." Through the mechanism formed by the UN Climate Change Conferences, the international community has lent a helping hand to low-carbon development in Africa, trying to change the energy

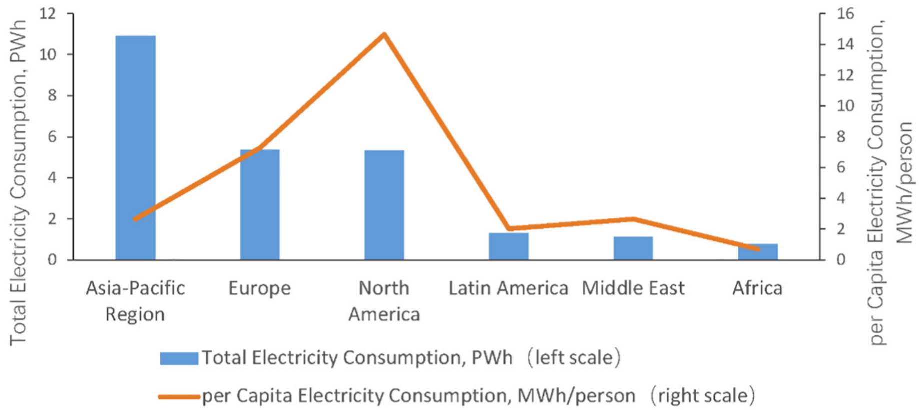

Fig. 2. Electricity consumption in Africa as the comparison with other regions in the world 2016 (British Petroleum, 2018a; Worldometers, 2018).

structure in Africa through financial and subsidy system. On April 25, 2016, shortly after the Climate Change Conference held in Paris, 25 countries pledged at UN Headquarters in New York for investment of 1 trillion USD to developing countries, including many African countries, to accelerate development of PV resources (United Nations Climate Change, 2016). Scaling Solar is a "one-stop" program launched by International Finance Corporation (IFC) and the World Bank (WB), which supports the grid-connected solar PV projects of the private investment and offers services of the preliminary legal, regulatory and technical analysis. Besides, it also takes responsibility for project bidding work and helps project developers to achieve the balance between financial revenue and expenditure. The WB and IFC plan to achieve 1000 MW of solar PV power generation in Africa from 2018 to 2020.

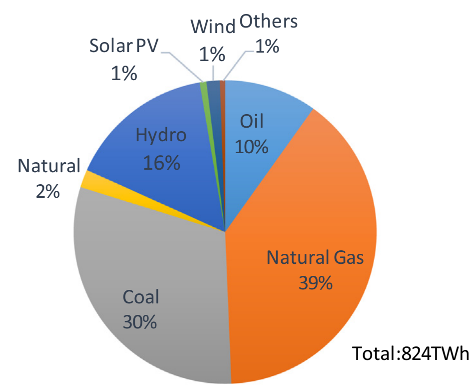

Fig. 3. Power mix in electricity generation in Africa in 2017 (British Petroleum, 2018a).

3.3.3. *Rapid decrease of PV price around the world*

Between 2010 and 2017, the price of PV modules on a global average dropped by a factor of 79, and over the same period, the efficiency increased from 15% to 25% (Battaglia et al., 2016) due to the technology advancement. Driven primarily by these two factors, the levelized cost of electricity (LCOE) generated using solar power in China decreased by 75% from 2010 to 2017, reaching as low as 0.5 RMB/kWh (US $0.077/kWh). The declining trend of capital costs of solar PV technology is expected to result in a further expansion of investment. Most of the solar PV panels rely on imports in Africa. Benefiting from the declining costs of solar PV in the international market, the capital costs for the development of solar farms also decreases in Africa. The LOCE of a solar PV project built in 2018 in Longonjo Province, Angola, reached below US $0.062/kWh.

3.4. *Threat analysis*

3.4.1. *Dominant position of the fossil fuels*

Traditional energy policies tend to favor the utilization of fossil fuels, impeding the entry of alternative energy sources due to institutional and economic reasons. In many cases, the energy institutions with past legitimization through the legal or governance framework, hold a stake in maintaining the dominant role of the fossil energy (Murombo, 2016). In addition, the policymakers pay more attention to the short-term growth of the economy than the long-term sustainable development, discouraging business leaders and investors from exploring the new path (Tomain, 2011). In South Africa, for example, the energy institutions including the Departments of Public Enterprises, Energy, and Finance, which developed jointly with the evolvement of the fossil-fuel industries in the country, play such a dominant role in policymaking that it is challenging to reform them (Pegels, 2010). In 2017, the global electricity generation amounted 25.0 PWh, 39.0% from coal and 23.7% from natural gas. As illustrated in Fig. 3, during 2017, the proportion of fossil energy in Africa's electricity production was 79%, while the PV power generation accounted only for 1% of the entire power sector. Development of solar PV on a large scale may unavoidably conflict with the interests of the dominant fossil-fuel-based generators.

3.4.2. *Potential ecological impacts associated with solar PV development*

The grasslands or desert areas in central and southern Africa are expected to be the ideal location for deployment of PV solar power. Large-areas of PV solar farms might have adverse impacts on local ecosystems if they are not properly planned. The traditional PV power generation modules require concrete buttress as support to arrange and adjust the tilt angle of the PV modules. Concrete buttress buried in the soil may damage the original ecological functions of soils after end-of-life solar PV recovery (Balali et al., 2017). The redistribution of water-heat induced by imperviousness and opacity of PV modules has a complicated effect on the vegetation restoration process (Huryna and Pokorný, 2016). In addition, most of the potential PV power stations are potentially located in grasslands in Africa, and light and water thus have more prominent impacts during the short lifetime of grass. Some scholars also concern the heat island effects in centralized solar PV farms (Barron-Gafford et al., 2016).

3.4.3. *Discontinuity of energy policies*

Although many countries in Africa have issued a series of energy policies, the consistent and effective implementation of these policies face potential risks as a result of influences of various complex factors at home and abroad (Arriola, 2009). One of the important uncertainties come from the instability during the political transitions. (Francois et al., 2015). For example, the "Arab Spring" happening in Tunisia, Algeria, Egypt, Libya in 2010 caused serious impacts on the economic growth and continuity of energy policies in these countries.

4. Countermeasures and suggestions for solar PV development in Africa

4.1. Adopt strong incentive policies

A transformation towards large-scale PV power needs strong policies to incentivize real changes and to break through the tradition of linguistic in fossil-fuel dominated energy framework. Wide choices of policy instruments for solar power such as tax reduction and exemption in the project life cycle, feed-in-tariff (Fit), and solar power portfolio requirements have been applied and tested in western or Asian countries, offering references for Africa. In China, the policy of "*Poverty alleviation through PV development*" has made great achievements in recent years. Enterprises or individuals are allowed to invest in PV power stations built on the land or roof provided by local residents a poverty-stricken area. Electricity generated will be incorporated into the power grid if there is any remaining after being used by themself. The part incorporated into the power grid will be granted at a favorable price guaranteed by the government and the Power Grid, and the corresponding revenues will allocated to investors and space owners (farmers) following a prearranged proportion. In this process, the Chinese local government plays a role in coordination, supervision and management. According to the Analysis Report of China PV Poverty Alleviation Industry, this policy stimulated addition of 8.5GW PV installed capacity in China in 2017, which exceeded the cumulative PV installed capacity of Australia in the same year. According to projection by the International Renewable Energy Agency (IRENA), the cumulative installed capacity of solar PV in West Africa, Eastern Africa and Southern Africa will reach 10GW, 4GW and 19GW by 2040, accounting respectively for 21%, 8% and 40% of the total capacity of electricity generation in Africa. To achieve this target would require a total investment of $23.1 billion, equal to 1.1% of total GDP in Africa as whole, based on a rough estimate of the capital cost of $700/kW. Such targets or even larger-scale deployment of PV solar power would not be effectively realized without strong incentive polices.

4.2. Promote hybrid solar power systems

Lack of strong and interconnected electric power grid system, hybrid solar power systems in Africa offer an important opportunity in distributed application to compensate for the intermittency of solar power by utilizing other locally available energy sources. In the hybrid system, the power outputs from solar PV can synergize with outputs from either diesel engines, gas turbines, or wind energy, which further enhance the competitiveness and utilization of solar PV power (Mandelli et al., 2016). For instance, with dispatching optimization, a hybrid system in Angola consisting of solar power, diesel engine and battery storage can realize an electricity price as low as US $0.056/kWh, only slightly higher than the electricity price of US $0.046/kWh in the local market (Economic and Commercial Counsellor's Office of the Embassy of the People's Republic of China in Angola, 2018). The hybrid system not only increases the integration of PV solar power and decreases its curtailment rate but also reduce the expense of diesel fuels (Brent and Rogers, 2010). Another case in Nigeria suggests that given the present loan rates and prices for diesel in the nation, a hybrid energy system with solar power can produce electricity with a lower price than that solely using diesel generators (Adaramola et al., 2014). Meanwhile, the hybrid systems can operate in the on-grid or off-grid mode, and such flexibility makes it suitable for the application in the rural and semi-urban areas in African countries.

4.3. Respond proactively to the potentially adverse environmental impacts of solar PV development

Some of the countermeasures can be taken during the whole process of solar PV development to reduce the adverse ecological impacts. The water and soil conservation needs particular attention for construction of solar PV farms in Africa. PV modules cleaning can use the waterless washing machine to reduce water consumption. Gravel pavement can be considered to replace the concrete pavement of the entire site. New technology for the support of PV modules like spiral steel pipe piles can be used to reduce damages to the soil. Spiral steel pipe piles are directly inserted into the ground through a drilling machine, which can be recycled after a lifetime of the PV power plant. The small footprints of spiral steel on the surface could avoid the large-area irreparable damage of the vegetation by the concrete foundation. This method has been adopted in several projects in Africa, such as the Longonjo PV power station in Angola (Electric, 2018b).

4.4. Seek opportunities in multilateral co-operation and the BRI framework

Africa's Agenda 2063 puts forward a prosperous Africa based on inclusive growth and sustainable green development (Office of the Special Adviser on Africa, 2015). The realization of such an agenda cannot be separated from the multilateral collaboration through the international community. Important opportunities exist for Africa to sustainably develop solar power through multilateral co-operation and the BRI framework. In 2017, the German G20 Presidency has called for a compact with Africa and prioritize the support for investment in Africa (Citinewsroom, 2018). It is critical that the measures taken by the international multilateral support and cooperation are in accordance with the United Nations 2030 Sustainable Development Goals (United Nations Development Programme, 2018) and the Paris Agreement (United Nations Climate Change, 2018). Integrating renewable energy including solar power into the agenda of new infrastructure investments offers an important opportunity to avoid the potentially costly trajectory locked-in with unsustainable, carbon-intensive infrastructure. Development of solar power in Africa should take advantage of existing African initiatives, such as Africa Renewable Energy Initiative (Gu et al., 2018), which aims at increasing renewable electricity in Africa by no less than 300 GW by 2030 (Mutanga et al., 2018). Moreover, the recently launched BRI (Commission N D A R, 2015) aims to promote green and low-carbon infrastructure along different economic corridors linking eastern Asia and Africa. Mutual benefits are expected for China-Africa energy cooperation, particularly in the development of solar power.

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References

Abolhosseini, S., Heshmati, A., 2014. The main support mechanisms to finance renewable energy development. Renew. Sust. Energ. Rev. 40, 876–885.
Adaramola, M.S., Paul, S.S., Oyewola, O.M., 2014. Assessment of decentralized hybrid PV solar-diesel power system for applications in Northern part of Nigeria. Energy Sustain. Dev. 19, 72~82.
African Development Bank Group, 2013. African Development Report 2012. Toward Green Growth in Africa Tunis-Belvedere.
Akinlo, A.E., 2008. Energy consumption and economic growth: evidence from 11 Sub-Sahara African countries. Energy Econ. 30 (5), 2391–2400.
Amankwah-Amoah, J., 2015. Solar energy in Sub-Saharan Africa: the challenges and opportunities of technological leapfrogging. Thunderbird Int. Business Rev. 57 (1), 15–31.
Arriola, L.R., 2009. Patronage and political stability in Africa. Comp. Political Stud. 42 (10), 1339–1362.
Baker, L., Sovacool, B.K., 2017. The political economy of technological capabilities and global production networks in South Africa's wind and solar photovoltaic (PV) industries. Polit. Geogr. 60, 1–12.
Balali, M.H., Nouri, N., Omrani, E., et al., 2017. An overview of the environmental, economic, and material developments of the solar and wind sources coupled with the

energy storage systems. Int. J. Energy Res. 41 (14), 1948–1962.
Barron-Gafford, G.A., Minor, R.L., Allen, N.A., et al., 2016. The photovoltaic heat Island effect: larger solar power plants increase local temperatures. Sci. Rep. 6 (1).
Bartniczak, B., Raszkowski, A., 2019. Sustainable development in African countries: an indicator-based approach and recommendations for the future. Sustainability 11 (1), 22.
Battaglia, C., Cuevas, A., De Wolf, S., 2016. Energy Environ. Sci. https://doi.org/10.1039/C5EE03380B.
Brent, A.C., Rogers, D.E., 2010. Renewable rural electrification: sustainability assessment of mini-hybrid off-grid technological systems in the African context. Renew. Energy 35 (1), 257~265.
Brunet, C., Savadogo, O., Baptiste, P., et al., 2018. Shedding some light on photovoltaic solar energy in Africa – a literature review. Renew. Sust. Energ. Rev. 96, 325~342.
Chakamera, C., Alagidede, P., 2018. Electricity crisis and the effect of CO2 emissions on infrastructure-growth nexus in Sub Saharan Africa. Renew. Sust. Energ. Rev. 94, 945–958.
China PV Industry Association, 2018. The Report for China PV Industry Association 2017. http://www.chinapv.org.cn/annual_report/584.html.
Citinewsroom, 2018. G20 Compact with Africa Conference Opens in Berlin-Germany. http://citinewsroom.com/2018/10/30/g20-compact-with-africa-conference-opens-in-berlin-germany/.
Commission N D A R, 2015. Vision and Actions on Jointly Building Silk Road Economic Belt and 21st-Century Maritime Silk Road. http://en.ndrc.gov.cn/newsrelease/201503/t20150330_669367.html.
Economic and Commercial Counsellor's Office of the Embassy of the People's Republic of China in Angola, 2018. Invest in Angola. http://big5.mofcom.gov.cn/gate/big5/mn2.mofcom.gov.cn/article/aboutus/contractus/200411/20041100007969.shtml.
Dongfang Electric, 2016. Bosnia and Herzegovina:Handover: The First Coal Fired Power Staion in EU by DEC. https://mp.weixin.qq.com/s/_UkNYNburSbSqDuqN0-9GQ.
Dongfang Electric, 2018a. Handover: First Power Plant in Angola by DEC. https://mp.weixin.qq.com/s/CGVIsfV–1WqZWsFZsdq8w.
Dongfang Electric, 2018b. BRI:Footprint for DEC in Africa. https://mp.weixin.qq.com/s/Eix50nLCVwgqYmy9XyoVuA.
Fereidoon, P.S., 2013. Evolution of Global Electricity Markets: New Paradigms, New Challenges, New Approaches. AP Elsevier.
Bloomberg New Energy Finance, 2018. BNEF Expects 34 Percent Fall in PV Module Prices this Year Due to Overcapacity. https://www.photon.info/en/news/bnef-expects-34-percent-fall-pv-module-prices-year-due-overcapacity.
Francois, P., Rainer, I., Trebbi, F., 2015. How is power shared in Africa? Econometrica 83 (2), 465~503.
Global Energy Statisitcal Yearbook, 2018. https://yearbook.enerdata.net/electricity/electricity-domestic-consumption-data.html.
Gu, J., Renwick, N., Xue, L., 2018. The BRICS and Africa's search for green growth, clean energy and sustainable development. Energy Policy 120, 675–683.
British Petroleum (BP), 2018b. BP Statistical Review of World Energy. https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-renewable-energy.pdf.
Huryna, H., Pokorný, J., 2016. The role of water and vegetation in the distribution of solar energy and local climate: a review. Folia Geobotanica 51 (3), 191–208.
Jadhav, A.S., Chembe, D.K., Strauss, J.M., et al., 2017. Status of solar technology implementation in the Southern African developing community (SADC) region. Renew. Sust. Energ. Rev. 73, 622~631.
van Kempen, L., Muradian, R., Sandóval, C., et al., 2009. Too poor to be green consumers? A field experiment on revealed preferences for firewood in rural Guatemala. Ecol. Econ. 68 (7), 2160–2167.
Labordena, M., Patt, A., Bazilian, M., et al., 2017. Impact of political and economic barriers for concentrating solar power in Sub-Saharan Africa. Energy Policy 102, 52~72.
Mandelli, S., Barbieri, J., Mereu, R., et al., 2016. Off-grid systems for rural electrification in developing countries: definitions, classification and a comprehensive literature review. Renew. Sust. Energ. Rev. 58, 1621~1646.
Martlnez-Alier, J., 1995. The environment as a luxury good or "too poor to be green". Ecol. Econ. 13, 1995) 1–10.
Murombo, T., 2016. Legal and policy barriers to renewable and sustainable energy sources in South Africa. J. World Energy Law Business 9 (2), 142–165.
Mutanga, S.S., Quitzow, R., Steckel, J.C., 2018. Tackling energy, climate and development challenges in Africa. Economics 12, 1–14. https://doi.org/10.5018/economics-ejournal.ja.2018-61.
Njoh, A.J., Etta, S., Ngyah-Etchutambe, I.B., et al., 2019. Opportunities and challenges to rural renewable energy projects in Africa: lessons from the Esaghem Village, Cameroon solar electrification project. Renew. Energy 131, 1013~1021.
Office of the Special Adviser on Africa, 2015. Agenda 2063. http://www.un.org/en/africa/osaa/peace/agenda2063.shtml.
Onuoha, G., 2015. A 'rising Africa' in a resource-rich context: change, continuity and implications for development. Curr. Sociol. 64 (2), 277~292.
Opiyo, N., 2016. A survey informed PV-based cost-effective electrification options for rural sub-Saharan Africa. Energy Policy 91 (1~11).
Pegels, A., 2010. Renewable energy in South Africa: potentials, barriers and options for support. Energy Policy 38 (9), 4945–4954.
Perez, C., Roncoli, C., Neely, C., et al., 2007. Can carbon sequestration markets benefit low-income producers in semi-arid Africa? Potentials and challenges. Agric. Syst. 94 (1), 2~12.
Pillot, B., Muselli, M., Poggi, P., et al., 2017. On the Impact of the Global Energy Policy Framework on the Development and Sustainability of Renewable Power Systems in Sub-Saharan Africa: The Case of Solar PV.
Pueyo, A., 2018. What constrains renewable energy investment in Sub-Saharan Africa? A comparison of Kenya and Ghana. World Dev. 109, 85–100.
Quansah, D.A., Adaramola, M.S., Mensah, L.D., 2016. Solar photovoltaics in sub-Saharan Africa – addressing barriers, unlocking potential. Energy Procedia 106, 97~110.
Solargis, 2018. Download Solar Resource Maps and GIS Data for 180+ Countries. https://solargis.com/maps-and-gis-data/download.
Sulemana, I., James Jr., H.S., Valdivia, C.B., 2016. 2016. Perceived socioeconomic status as a predictor of environmental concern in African and developed countries. In: Journal of Environmental Psychology.
Taele, B.M., Mokhutšoane, L., Hapazari, I., et al., 2012. Grid electrification challenges, photovoltaic electrification progress and energy sustainability in Lesotho. Renew. Sust. Energ. Rev. 16 (1), 973~980.
TaoWang Yuechen, Z., 2016. China-Africa Cooperation on African Solar Energy Development. Global Review, 2016(06). pp. 110–131.
Tomain, J.P., 2011. Ending Dirty Energy Policy: Prelude to Climate Change. 6. Cambridge University Press.
United Nations Climate Change, 2016. 25 Countries Pledge to Facilitate USD 1 Trillion of Investment in Solar. https://unfccc.int/news/25-countries-pledge-to-facilitate-usd-1-trillion-of-investment-in-solar.
United Nations Climate Change, 2018. The Paris Agreement. https://unfccc.int/process/the-paris-agreement/what-is-the-paris-agreement.
United Nations Development Programme, 2018. Sustainable Development Goals. http://www.undp.org/content/undp/en/home/sustainable-development-goals.html.
United Nations Environment Programme, 2018. Global Trends in Renewable Energy Investment 2018. http://www.greengrowthknowledge.org/resource/global-trends-renewable-energy-investment-report-2018.
Wolde-Rufael, Y., 2006. Electricity consumption and economic growth: a time series experience for 17 African countries. Energy Policy 34 (10), 1106–1114.
Worldometers, 2018. World Population-by-Region. http://www.worldometers.info/world-population/population-by-region/.
Yonghong, Z., 2013. Impetus and Constraints behind African Renewable Energy Development. West Asia and Africa, 2013(05). pp. 73–89.
Zubi, G., Fracastoro, G.V., LujanoRojas, J.M., et al., 2018. The unlocked potential of solar home systems: an effective way to overcome domestic energy poverty in developing regions. Renew. Energy. https://doi.org/10.1016/j.renene.2018.08.093.